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Dynamic Analysis of Product Lifecycle and Sea/Air Modal Choice: Evidence of Export from Japan*

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Contents

Abstract

Here, we test the hypothesis that commodities at their peak valuation are transported by air, while those at their inception and maturity are shipped by sea, as well as the theory that shippers choose air to transport high-valued commodities. We empirically investigated how the product lifecycle of commodities is reflected by shippers' choices of air over seaborne transportation. We also assumed that commodities that achieved substantial innovation in their lifecycles would be moved by air transportation so that these commodities could reach targeted markets as quickly as possible to avoid the opportunity costs that might be generated by missed business chances. We constructed two sets of unbalanced panel data of 14 commodities for 24 years drawn from Japan's customs, demographic, and international statistics. By estimating structural equation systems that consisted of commodity-specific export and export air ratio functions, we found that the product lifecycle of cargo outgoing from Japan exactly matched the upward and downward movement of the air ratio.

Key Words : Product Lifecycle, Modal Choice, Structural Equations

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I. Brief Overview of Japanese Economy and Logistics

Japan has experienced several economic phases over the past 20 years, including the "bubble" economy (around the year 1990), followed by a long-term recession that the Japanese call the "lost 20 years," which included a "deflation-spiral," the "inflation of crude oil (early 2008)" and the "Lehman shock in 2008." During the latter, many companies that had led industries in Japan went bankrupt or reorganized. During the "lost 20 years," stock prices fell and the Japanese yen grew stronger over time. These trends were followed by an increase in Japanese foreign investment in Asian countries such as China, Thailand, Indonesia, and Vietnam, and by the relocation of some company headquarters and/or factories to these foreign countries. During the same period, Japan's economy came to depend on imports rather than exports, and its international trading balance became negative due to this increase in imports, especially from East Asian countries.

In accord with these shifts in Japanese economic activities from domestic to international markets, manufacturers and companies had to develop international logistics systems, which have played an important role in their supply chain management (SCM). While some companies relegated the operation of international logistics or SCM to third-party logistics providers, others internalized these operations. For example, Toyota Motor Corp. manufactures and assembles car parts that are commonly used over its product lineup, such as wire harnesses, brake pedals, and antennas, in Vietnam. The in-process goods are then imported into Japan where the cars are assembled.[1] It is commonly known that some manufacturers relegate logistical activities to logistics-service providers (LSPs) associated with shipping companies, freight forwarders, and airlines. Air freighters such as FedEx and UPS have evolved high-quality SCM systems called integrators, but not many manufacturers of middle- or lower-quality goods use them. Instead, in light of the valuation of their cargo, they use LSPs.

Regardless of whether a manufacturer chooses an LSP or an integrator, they must decide on the mode of transportation for trans-ocean and/or trans-continental exports or imports by negotiating with LSPs. In the case of

1) From an author interview at Toyota Motor Vietnam, Hanoi, Vietnam, in July 2008.

Japan, the transportation modes for international export/import are limited to air and seaborne transportation, since Japan has no land-based link to the continents.

The shippers must bear higher expenditures when they need products shipped quickly, since short-time delivery necessitates the speed afforded by air transportation, which generally costs more than sea shipping. According to traditional international trade theories, such as the Heckscher–Ohlin model, a commodity with comparative cost competitiveness is exported to a foreign country. In such a case, it is natural to expect that the commodity will be exported by sea in order to take advantage of the comparatively low tariff rates. However, it is possible for the generalized cost of seaborne transportation to exceed that of air transportation due to the opportunity costs of missed business chances, high interest rates, and high insurance costs that accompany long voyages. Shippers may thus choose air transportation when the generalized cost of air transportation is cheaper than that of seaborne transportation. If we think of shippers' choices of air or seaborne transportation based on the idea of generalized costs mentioned above, the valuation of a commodity is not the absolute determinant of the selected mode of transportation.

II. Purpose of Analysis

In this paper we reduce the idea of product lifecycles to the over-time changes in the valuations of commodities, and then analyze whether the lifecycles match the changes in air ratios in the case of exports. The methodologically outstanding features of our analyses are that they bridge the following three ideas: (1) the idea of ordinary export functions; (2) the air ratio that is much concerned with conditional factors demanded of air transportation; and (3) the idea of the product lifecycle. We regressed the air-ratio variable on the cargo-valuation dummy variables as well as other variables common for supply- and factor-demand scenarios.

The cargo-valuation variables are a series of dummy variables. The "peak year dummy" takes the value 1 when a certain commodity is at its peak valuation, and the "one-year post-peak dummy" takes the value 1 for the year following the peak. There are five in the series of peak year dummies: two years before, one year before, the peak, one year after, and up to five years after the peak. By estimating and testing the hypothesis of the coefficients of these dummies, we can approximate how long each stage of the product lifecycle lasts for exports in Japan. In the following section we review previous studies of cargo pricing (i.e., freight rate) theory and product lifecycle management. In Sections IV and V we demonstrate our empirical model and the dataset, respectively, and in Section VI we carry out the econometric analysis based on the models and data in Section IV. We also evaluate the empirical results, and in Section VII we summarize the contributions of our study.

III. Literature Review of Cargo Pricing Theory and Product Lifecycle Management

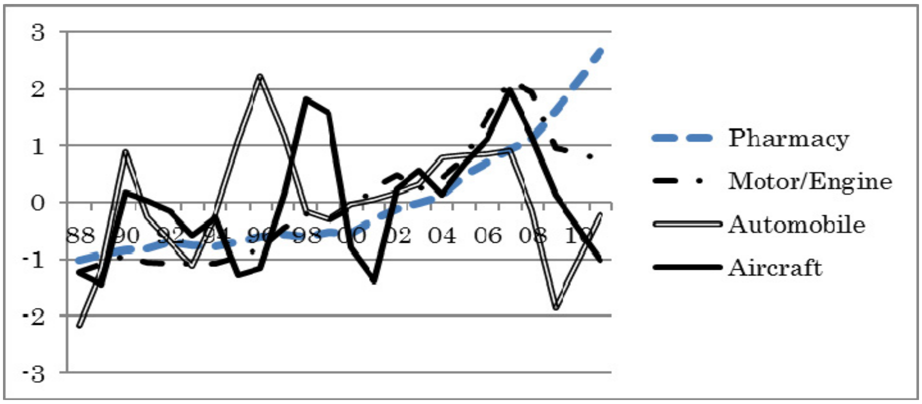
The pricing rule for air and seaborne cargo is easily explained by the traditional theory of transportation economics. Generally, the freight rate that traffic can bear is the generalized cost of transportation divided by the valuation of the cargo. This implies that the price of cargo is determined by the price-discrimination rule and the handling costs of commodities.

Klepper (1996) developed a model that explained the evolution of an industry from birth to maturity and theoretically showed the mechanism underlying how a product lifecycle takes place and is terminated. He pointed out that the size of a firm plays an important role in the next innovation; e.g., a large firm with a sufficient budget would supply products with lifecycles. Miyashita (2009; 2010), based on the results of several empirical studies, reported that shippers chose seaborne logistics only, both seaborne and air in a complementary manner, or air only. He bridged these modal choice behaviors with the product lifecycle theory.

Gecevska et al.(2010) stated that SCM was one of the operations that should be managed as a part of the product lifecycle management (PLM) across a business. Since logistics activities are deeply related to SCM, the modal choice of export plays an important role in PLM. These researchers emphasized that “speed” is important in getting a competitive advantage over rivals, implying that air transportation is very important for managers looking to establish a competitive advantage for their products.

Figure 1 illustrates that cargo valuations can change cyclically except for pharmacy that shows an exponential trend only (dotted line). In this paper, we will assume Klepper's idea that the commodities of large industries follow a product lifecycle. We then highlight the characteristics of lifecycles of specific commodities, and test the hypothesis that the commodities at their peak valuation are transported by air, while those at their birth and maturity are shipped by sea.

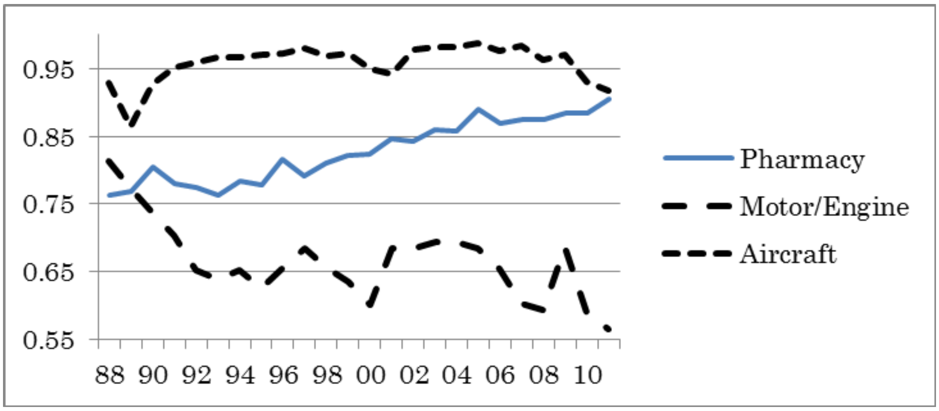
<Figure 1> Time series changes in commodities' valuations (import case).



The vertical axis shows the standardized (mean=0) valuations and the horizontal axis shows the fiscal years.

In addition, the air ratio itself has a characteristic of cyclical change at a particular level between 0 and 1. Figure 2 shows that the air ratio (see Section III) also has both cyclical and time-trend characteristics (especially a positive trend for medicine and a negative one for motors).

<Figure 2> Changes in the air ratio with/without trends



The virtual axis shows the standardized valuations. The horizontal axis shows the fiscal years.

In summary, we have four categories concerning the relationship between commodity valuations and the air ratio (Table 1).

<Table 1> Classification of commodity samples with/without trend or cycles

	Cycle	No cycle
Trend	Pharmacy (air ratio), Engines (valuation, air ratio)	Pharmacy (valuation)
No Trend	Aircraft (air ratio, valuation) Automobile (valuation)	

Commodities indifferent to peaks/off-peaks such as gold and precious stones are omitted from the present analysis. The words in parentheses at the top-left partition indicate the air ratio of pharmacy changes with cycles and trends. Engines' air ratio and valuation also change with cycles and trends.

Regarding the commodities in Table 1, we can infer that air and seaborne service are substitutes for commodities with cycles and no trend, and complements for commodities with both cycles and trend. In this case, the up-slope trend is caused by technical progress and/or increases in individual income or the GDP. Considering these facts regarding commodity characteristics, we will have to incorporate the idea of commodity-specific analyses into our empirical models such as commodity-fixed effects.

Vernon's product lifecycle theory (1966) followed by Vernon (1979) consists of three stages: new product, maturing product, standardized product. Miyashita (2009) added one more stage: rationalized product. He empirically studied the systems of inter-regional cargo flows by associating the idea of product differentiation with the air ratio. However, the relationship between the peak of the air ratio and the product lifecycle were not analyzed. Here we try to analyze how and to what extent the product lifecycle is reflected by the air ratio for commodities. We do not perform an origin/destination-specific analysis, in order to maintain a sufficient number of samples in the statistical sense.

IV. The Model

We first construct the export air ratio functions together with traditional export functions. Usually, empirical analyses of modal choices employ logit-type discrete choice models using disaggregate data like Ben-Akiva and Lerman (1985), and Train (2009). Ben-Akiva and de Jong (2013) suggested that disaggregate and aggregate data cannot be combined in the same model in principle, but allowed it was feasible by calibrating the parameter obtained from the disaggregate model.

In our case, since the availability of the data was limited, we used only the aggregate data, and did not employ the logit model. Instead, we used air ratio as a dependent variable. In doing this, we expected a better result as to whether product lifecycle affected the sea/air split than we would obtain using a zero-or-nothing binary dependent variable.

The definition of the air ratio (AR_{it}) is as follows:

$$AR_{it} = \frac{ACV_{it}}{ACV_{it} + SCV_{it}} \quad \left(i = commodity, t = year\right) \tag{1}$$

where ACV_{it} and SCV_{it} are the commodity valuations that are exported by air or sea. The determinants of this air ratio can be approximated by deriving the conditional factor demand, because both air and seaborne services are input demands of shippers. Assuming that competitive Japanese shippers (here, exporters) minimize their costs subject to a certain fixed amount of cargo, the conditional factor demands can be obtained by taking the first order condition of the Lagrange function (Eq. 2) in terms of inputs $(x_i's)$ and a Lagrange multiplier (φ), and a second-order condition such that the Hessian matrix composed of the second-order differentiated terms is positive definite.

$$\min_{x_1,\ldots,x_j,\varphi} L = \sum_{i=1}^{j} w_i x_i + \varphi\left\{Q^*(x_i)\right\} \tag{2}$$

The conditional factor demands for x_j can be written in the generalized form:

$$x_j = f\left\{(+)Q, (-)w_j, (+)\sum_{-j} w_{-j}\right\} \tag{3}$$

where Q is the cargo traffic, and w_j and w_{-j} are the input prices. The plus and minus in the parentheses are expected signs assuming that an input is a substitute for the others. In our study, w_j and w_{-j} are assumed to be the valuations of air and seaborne services, respectively; that is, ACV_{it} and SCV_{it} and the determinants of the air ratio will be Q, w_j and w_{-j}.

Again,

$$AR_{it} = \frac{ACV_{it}}{ACV_{it} + SCV_{it}} = \frac{w_j}{w_j + w_{-j}} \tag{1'}$$

If we assume that the production technology follows the Cobb-Douglas form, such that:

$$Q^* = x_j x_{-j} \tag{4}$$

From the first-order condition of the Lagrange function (Eq. 2), we obtain:

$$w_j = \varphi x_{-j} \text{ and } w_{-j} = \varphi x_j \tag{5}$$

The conditional factor demands that we obtain by the first-order condition of Eqs. (2) and (4) are as follows:

$$x_j = \left(\frac{Qw_{-j}}{w_{-j}}\right)^{\frac{1}{2}} \text{ and } x_{-j} = \left(\frac{Qw_j}{w_{-j}}\right)^{\frac{1}{2}} \tag{6}$$

Substituting Eqs. (5) and (6) into Eq. (1)', we obtain:

$$AR_{it} = \frac{x_{-j}}{x_j + x_{-j}} = \left(\frac{\operatorname{Ref} P_t^{\frac{air}{sea}}}{\operatorname{Ref} P_t^{\frac{air}{sea}} + \frac{1}{\operatorname{Ref} P_t^{\frac{air}{sea}}}} \right). \tag{7}$$

where $\operatorname{Ref} P_t^{air/sea}$ is the ratio of air/sea cargo valuations $(that\, is, w_j / w_{-j})$.

Taking the derivative of Eq. (7) with respect to $\operatorname{Ref} P_t^{air/sea}$, we obtain:

$$\frac{\partial AR_{it}}{\partial \operatorname{Ref} P_t^{\frac{air}{sea}}} = \left\{ 1 + \left(\operatorname{Ref} P_t^{\frac{air}{sea}} \right)^2 \right\}^{-\frac{3}{2}} > 0. \tag{8}$$

Therefore, the sign of air valuation variable is positive in the air-ratio function.

Our export functions are constructed by following ordinary microeconomic theory. They can be derived by assuming that Japan maximizes its utility subject to its budget constraints each year. The explanatory variables are the price of exported commodities, domestic prices, and system-wide world GDP, with the exchange rate as a control variable. The export function of general form is as follows:

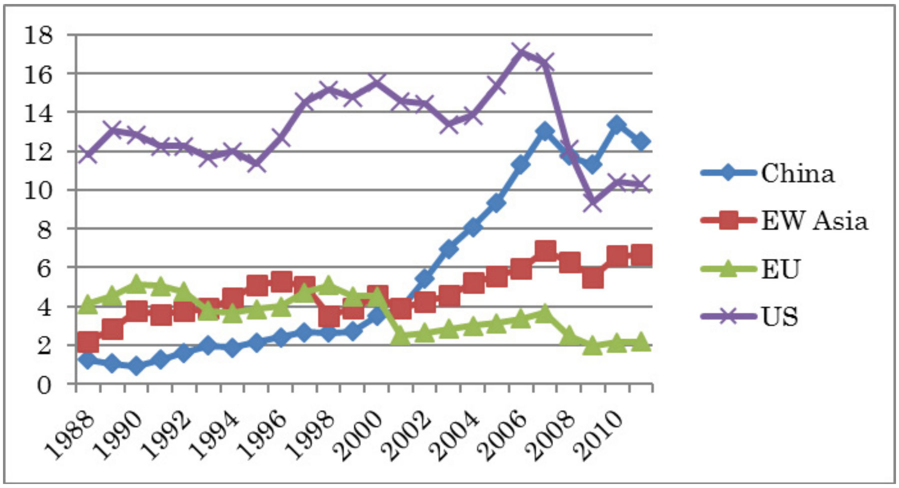
$$Q_{it} = \left\{ (+)\frac{WGDP_t}{PJ_{it}}, (-)\frac{JPNyen_t}{USD_t}, (+)\frac{PW_{it}}{PJ_{it}} \right\}, \tag{9}$$

where Q_{it} is the exported cargo of commodity *i* in year *t*, $WGDP_t$ is the system-wide world GDP exempting Japan in year *t*, $JPNyen_t$ is the Japanese yen in year *t*, USD_t is the U.S. Dollar in year t, PJ_{it} is the price of domestic goods in year deflated by the retail price index, and PW_{it} is that of foreign goods in year *t*.

As for PJ_{it}, we prepared Japan's retail price index and the Nikkei stock price index, and used the one better fitted from the statistical point of view.

Japan used to export goods mainly to the U.S. and Europe, but has more recently been exporting to China and South-East Asian countries (Figure 3).

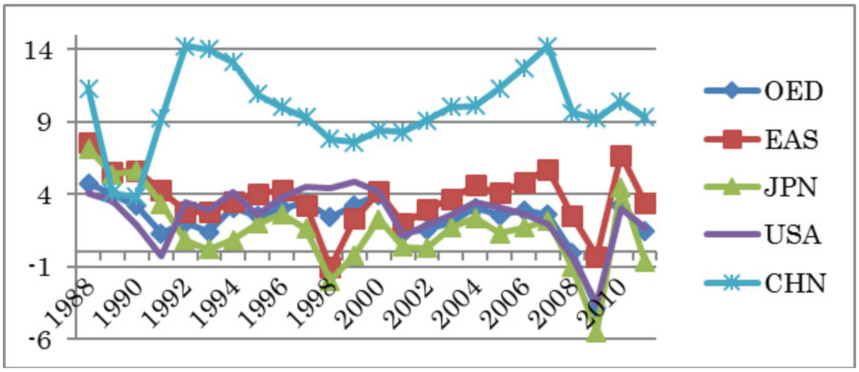
<Figure 3> Changes in total valuations of commodities exported from Japan



The vertical axis indicates U.S. dollars (billions) and the horizontal axis is fiscal years. Source: Ministry of the Treasury, Japan.

The GDPs of Japan's "long-term" trading partners have moved almost the same way, but China has shown a different growth rate curve (Figure 4). The correlations among the GDP grows rates of these countries or regions are shown in Table 2.

<Figure 4> GDP growth rates of each country/region



OED, OECD countries; EAS, Eastern Asia; JPN, Japan; USA, the United States; CHN, China. Source: World Bank.

<Table 2> Correlation coefficients among countries/regions' GDP growth rates

	OED	EAS	JPN	USA	CHN
OED	1.000				
EAS	0.648**	1.000			
JPN	0.783**	0.902**	1.000		
USA	0.881**	0.293	0.446*	1.000	
CHN	-0.068	0.068	-0.159	0.060	1.000

**: significant at 1% level, *: at 5% level. Abbreviations are explained in Figure. 4.

With this replacement, Eq. (9) will be Japan's supply function to the world. The modified version of Eq. (9) is as follows:

$$Q_{it} = \left\{ (+)\frac{JGDP_t}{PJ_{it}^k}, (-)\frac{JPNyen_t}{USD_t}, (+)\frac{PW_{it}}{PJ_{it}^i} \right\}. \tag{10}$$

Again, let PW_{it}^k be a numeraire. Eq. (6) will then be rewritten as follows:

$$Q_{it} = \left\{ (+)\frac{JGDP_t}{PJ_{it}^k}, (-)\frac{JPNyen_t}{USD_t}, (-)PJ_{it}^i \right\}. \qquad (11)$$

Unlike Eq. (11), the sign of PJ_{it}^i will be specified as being negative if we take the logarithm.

When Japan's shippers think of trading goods with foreign countries, they have to consider which transportation mode to use, air or seaborne. Following this simultaneous decision-making by shippers, we construct system-equation models as follows:

System of export function

$$\ln(Q_{it}^{export}) = \alpha_0 + \alpha_1 \ln(JGDP_t) + \alpha_2 \ln\left(\frac{JPNyen_t}{USD_t}\right) + \alpha_3 \ln(PJ_{it}^i) + \sum_m \alpha_{4m} DCOM_m + \varepsilon_t \qquad (12)$$

$$\ln(AR_{it}^{export}) = \beta_0 + \beta_1 \ln(Q_{it}^{export}) + \beta_2 \ln\left(\text{Ref } P_t^{\frac{air}{sea}}\right) + \beta_{3\tau} \sum_\tau DVAL_\tau + \sum_m \beta_{4m} DCOM_m + \mu_t \qquad (13)$$

where $DVAL_\tau$ is the dummy variable that denotes the product lifecycles. $DVAL_0$ takes 1 when the valuation of commodities is at its peak; $DVAL_{-1}$ takes 1 for one-year before the valuation of commodities was peak; $DVAL_1$ takes 1 for one-year after, etc. We have five $DVAL_\tau$ variables, and subscript starts with −2 and ends with 5. $DVAL_m$ is the commodity-specific fixed effect dummy variable, and *m* denotes the type of commodity, such as pharmaceuticals, semi-conductors, etc.

V. The Data

Data was collected from Japan's custom classification statistics maintained by the Ministry of the Treasury. Retail price indices, standardized by the average of samples, were obtained from World Economic Outlook Databases (IMF). The dataset of exports is the balanced panel data of 10 commodities over a 24-year period. The number of sample observations is thus 240.

The commodities chosen here were the ones classified by a five-digit category in the custom classification. Goods that have no product lifecycle such as raw materials, bulk cargo, daily-supplies, etc., were omitted. Air ratios for such goods have always been under ten percent. Non-ferrous materials can sometimes be regarded as bulk cargo. However, while this was true in the 1990s, recently this category has included a bulk of precious metals. Therefore, the air ratio is unexpectedly high.

<Table 3> Descriptive statistics of continuous variables

Variables	**Average**	**S.D.**	**Minimum**	**Maximum**	**Median**
Export air ratio	0.487	0.344	0.030	0.999	0.386
Export cargo volume (000t)	70284.338	136641.390	1628.000	651568.234	9705764.000
Export reference price (air/sea, Yen)	33.056	56.320	0.001	336.457	18.006
Net GDP (Billion yen)	47.026	3.584	38.160	52.369	47.482
Exchange rate (Yen against USD)	114.246	15.712	79.807	144.793	114.921
Total population (000000)	126.281	1.628	122.745	128.057	126.797
Export price index (Yen)	100.107	3.092	90.290	104.140	100.760

S.D.: standard deviation.

VI. Empirical Results

We first estimated simultaneous Eqs. (12) and (13) by three-stage least squares, and detected an existing heteroscedasticity.[2)] The results are presented in Table 4.

<Table 4> Estimated results of export and air ratio functions

Air Ratio Function			
Variable Name	**Estimated Coefficient**	**T-Ratio**	**p-Value**
Cargo Volume	0.119	8.796	0.000
Cargo valuation ratio (air/sea)	0.218	11.770	0.000

2) We carried out the heteroscedasticity test. The Breusch and Pagan chi-square value of export function and exp ort air ratio function were 145.37(16) and 159.20(16), respectively. The degrees of freedom are in parentheses, and all the null hypotheses of homoscedasticity were rejected at the 1% level.

Two-year before the peak	0.225	1.282	0.200
One-year before the peak	0.504	2.871	0.004
Peak year of commodity valuation	0.541	3.083	0.002
One-year after the peak	0.554	3.158	0.002
Two-year after the peak	0.569	3.035	0.002
Three-year after the peak	0.574	3.061	0.002
Four-year after the peak	0.562	2.990	0.003
Five-year after the peak	0.493	1.728	0.084
Raw fish	-1.165	-9.660	0.000
Pharmacy	0.111	0.908	0.364
Nonferrous metals	-0.858	-7.355	0.000
Motors/Engines	-0.858	-7.355	0.000
Semi-conductors	0.776	6.328	0.000
Gold♯♯	1.462	11.530	0.000
CONSTANT	-3.331	-14.140	0.000
Export Function			
Export price index♯	-1.174	-2.556	0.011
Japanese yen/USD	0.480	1.429	0.153
Japan's GDP♯	3.485	4.189	0.000
Raw fish	4.225	14.900	0.000
Pharmacy	9.786	21.220	0.000
Pearls	10.374	22.500	0.000
Nonferrous metals	5.988	12.980	0.000
Motors/Engines	5.988	12.980	0.000
Audio Apparatus	9.971	21.640	0.000
Loud speakers, microphone	12.022	26.070	0.000
Semi-conductors	11.466	24.860	0.000
Gold♯♯	3.728	8.083	0.000
CONSTANT	-24.199	-3.520	0.000
SYSTEM R-SQUARE			0.994
TEST OF THE OVERALL SIGNIFICANCE CHI-SQUARE WITH 28 D.F			1245
P-VALUE			0.000

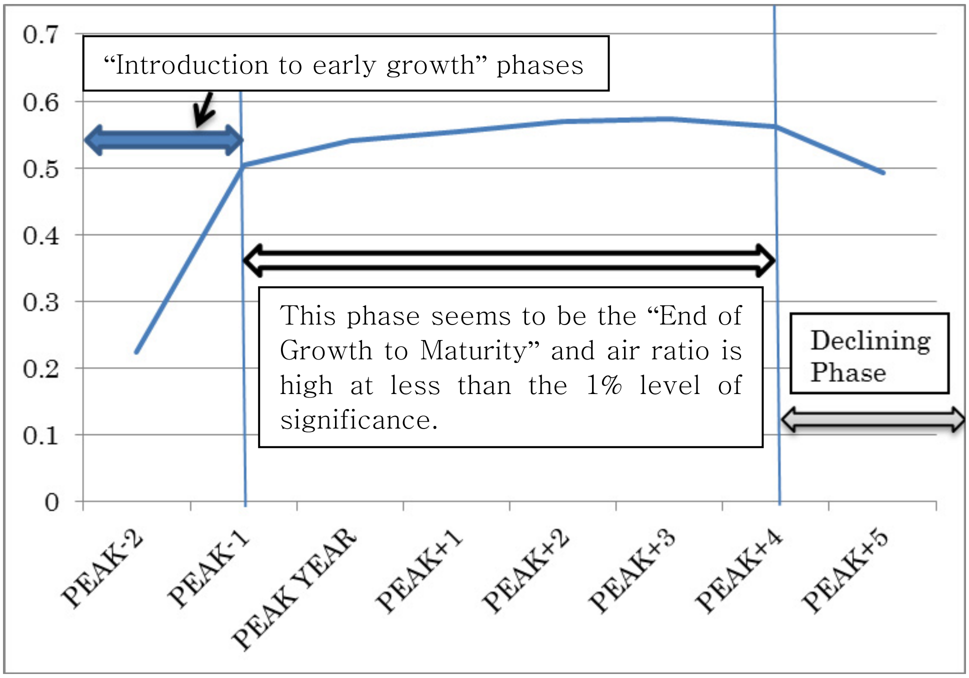
Note: N=240. ♯: deflated by average of retail price index. ##: Monetary gold is exempted. The benchmark of the fixed effect dummy variable is processed meat.

The parameters of export function are well matched with expectations. As for air ratio function, the sign of cargo volume is positive. If these cargos were less valuable or heavy goods, the sign of the parameter must be negative. Therefore, it is implied that the goods exported from Japan have been high-value light products.

Looking at the sign of $DVAL_\tau$ (see Section III), the shippers choose air transportation one year before their cargo values' peak, the peak year, and for four years after the peak. Therefore, commodities at or adjacent to their peak valuations in their product lifecycle tend to be transported by air for five years.

Figure 5 shows the changes in the coefficients of valuation dummy variables for export cases. It is apparent that the lifecycle of export cargo changes on a single-year basis, and it appears that the lifecycle of export cargo from the late growth period of a commodity to maturity continues beyond five years.

<Figure 5> Lifecycle of cargo valuation and choice of air/seaborne transportation.



The vertical axis shows the coefficients of the series of cargo valuation dummy variables.

VII. Concluding Remarks

Our study has two outstanding features: one is methodological, and the other has to do with our findings. The former is that we employed aggregate data for the modal-choice analysis and used the air ratio instead of a "0/1" type binary variable. By doing this, we were able to combine a modal choice model with the export function used in the macroeconomic literature. As a result, we were able to estimate the structural equation model that might well explain shippers' exporting behavior. We also expected that by using the air ratio model, the "gray zone"[3)] in which shippers choose either airline or liner shipping would be better explained than by employing the 0/1 binary model.

We hypothesized that this "gray zone" has arisen due to the product lifecycle of cargo. Our analysis implied that products at their peak value were transported by air for five years, and that these five years were likely to be around the end of the growth-to-maturity phase of the product lifecycle. This result is our second outstanding contribution.

The political implication of our paper is that since many kinds of industrial products have product lifecycles—regardless of whether they have patents valid for a certain period—both air- and seaports with industrial surrounding areas should be located adjacent to each other in order to respond to the industries' boom and decline phases; that is, for the purposes of "robustness" against the product lifecycle.

Our analysis might be useful to other island countries, such as Australia, New Zealand, Taiwan, the Philippines, etc. Of course, our study has some limitations, including the following: (1) we did not perform an origin / destination-specific analysis, nor include a time, distance variable; (2) we attempt to go no further than the current status: that is, the analysis of an individual good, or at least a group of goods. Therefore, our analysis may be far from practical reality, and address only the "macro-level" of evidence.

If we perform the analyses above, the sample number will decrease since the dataset we used here will be partitioned, but the estimated results may change between countries and economy blocks. Therefore, our results

3) Miyashita(2009), pp.129-130.

might be understood as "on average" analyses between Japan and other countries. Future studies are planned to overcome this limitation.*

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